An Earth Gravitational Model to Degree 2160: EGM2008

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# Progress since the IUGG 2007 Meeting in Perugia

- Re-iteration of $5' \times 5'$ area-mean terrestrial Δg predictions using PGM2007B as our reference model to 2160 was completed.

- Ocean-wide altimetry-derived Δg were estimated **independently** by DNSC and SIO/NOAA, using PGM2007B and its associated Dynamic Ocean Topography as reference models.

- Feedback from several members of the IAG/IGFS Joint Working Group on the performance of PGM2007A was received, evaluated, and corrective actions were taken where necessary (and possible).

- A new global $5 \times 5'$ Δg data set was compiled by January 8, 2008.

Our main focus:

- Calibrate our error estimates and perform the final iteration of the model's development, to produce EGM2008.
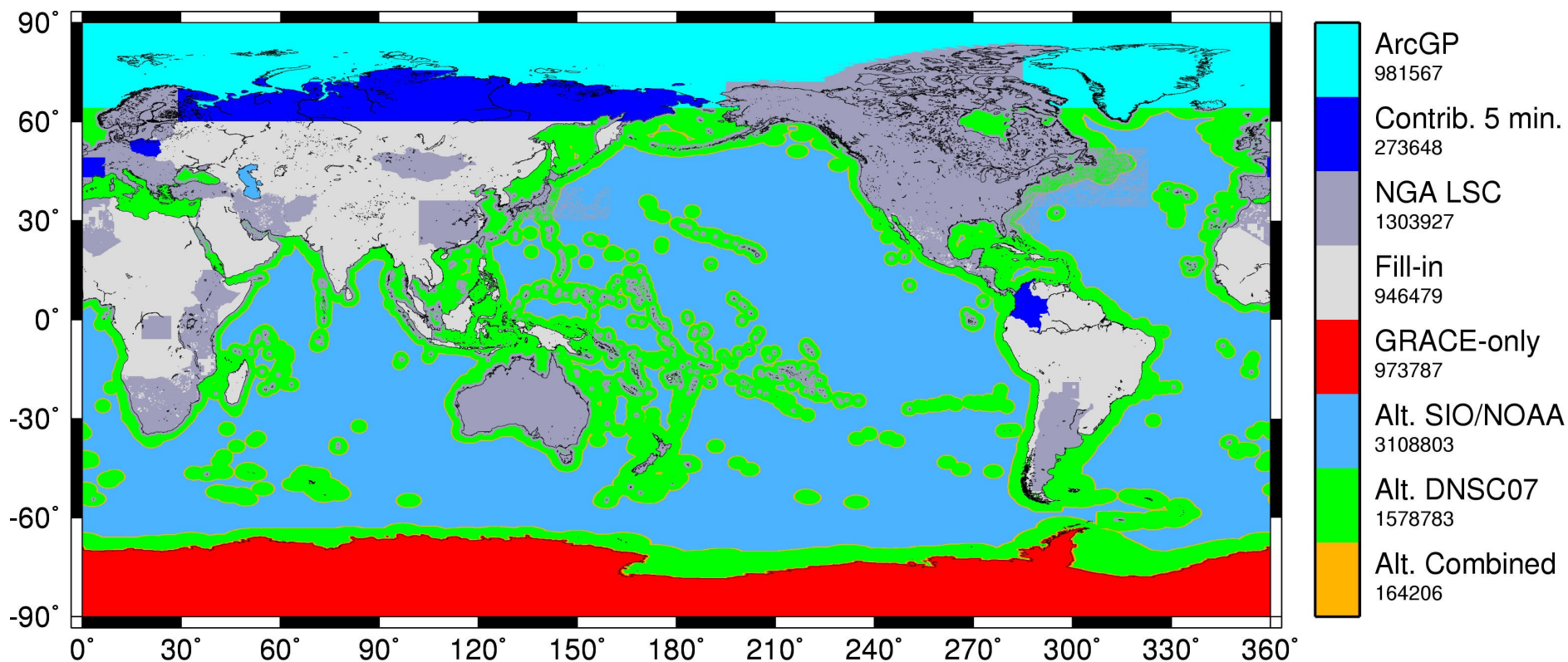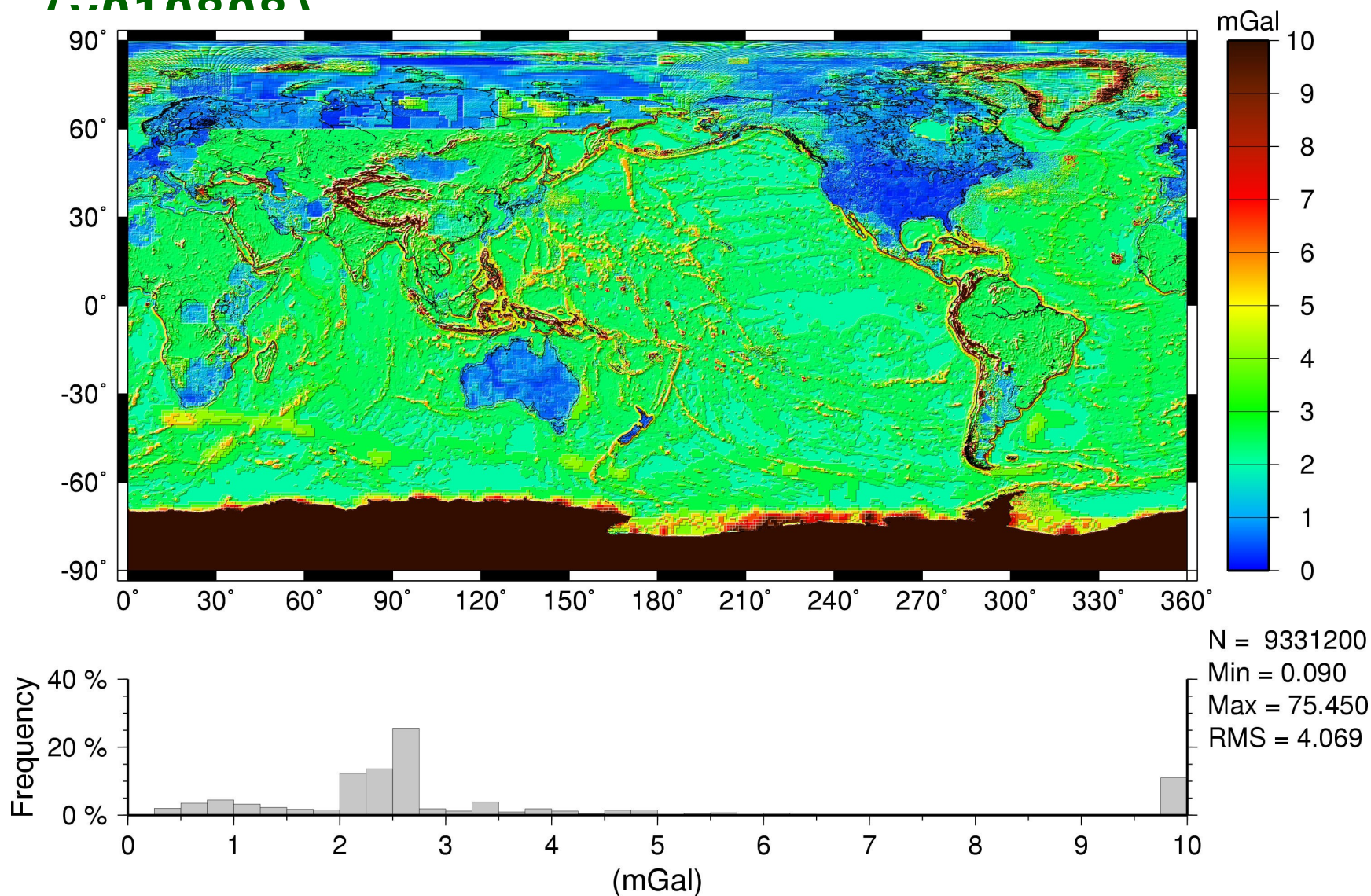
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▷ 5′✕5□ Δg Data Availability (v010808)
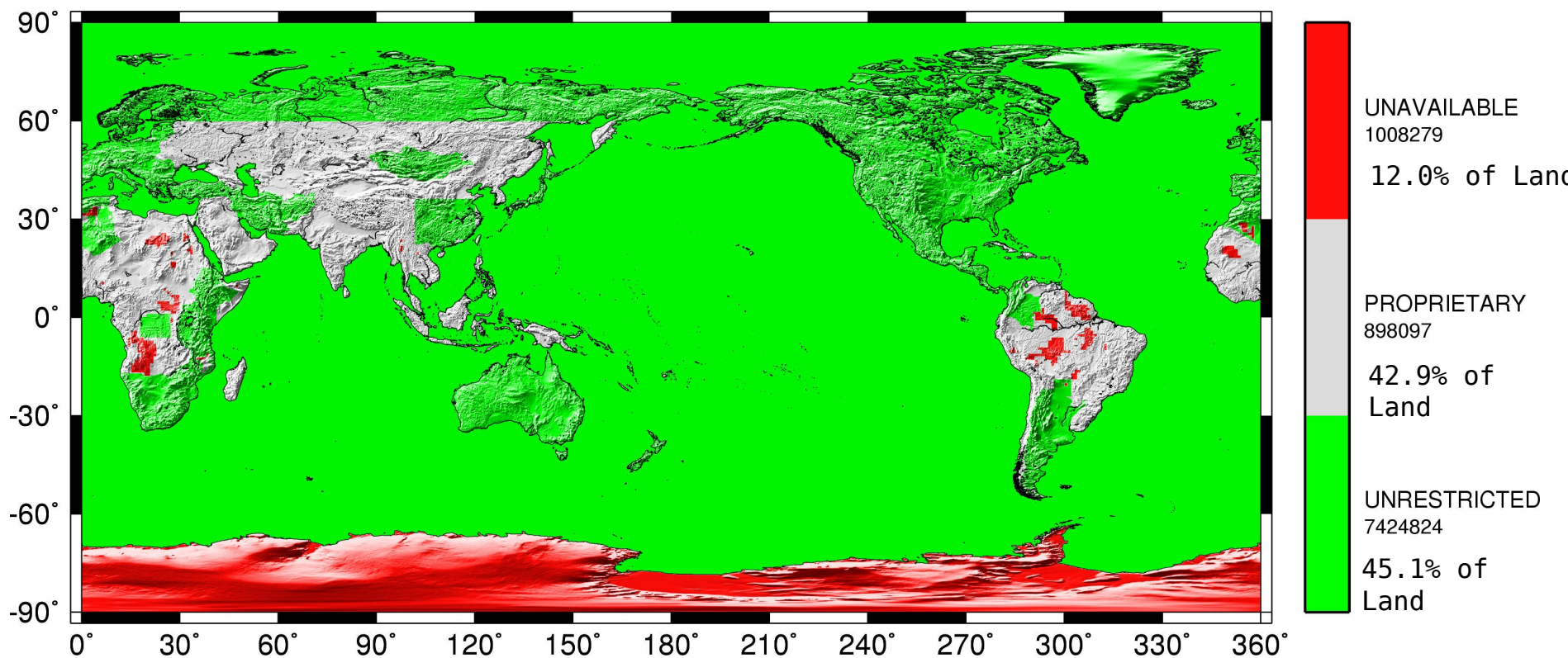
5ʹ×5ʹ Δg Data Sources (v010808)

▷ **5ʹ×5ʹ Δg Data Standard Deviations (v010808)**

N = 9331200
Min = 0.090
Max = 75.450
RMS = 4.069

▷ Statistics of 5′×5′ Δg Data of v010808 (mGal)

Source	% Area	Min.	Max.	RMS	RMS σ
ArcGP	3.0	-192.0	281.8	30.2	3.0
Altimetry	63.2	-361.8	351.1	28.4	3.0
Terrestrial	17.6	-351.9	868.4	41.2	2.8
Fill-in	16.2	-333.0	593.5	46.8	7.6
Non Fill-in	83.8	-361.8	868.4	31.6	2.9
All	100.0	-361.8	868.4	34.5	4.1
(φ, λ)		19.4°, 293.5°	10.8°, 286.3°		

Statistics refer to edited and downward continued gravity anomalies.

The area void of high quality 5′ data (~16% of the globe) is also the "roughest" area of the gravity anomaly field.
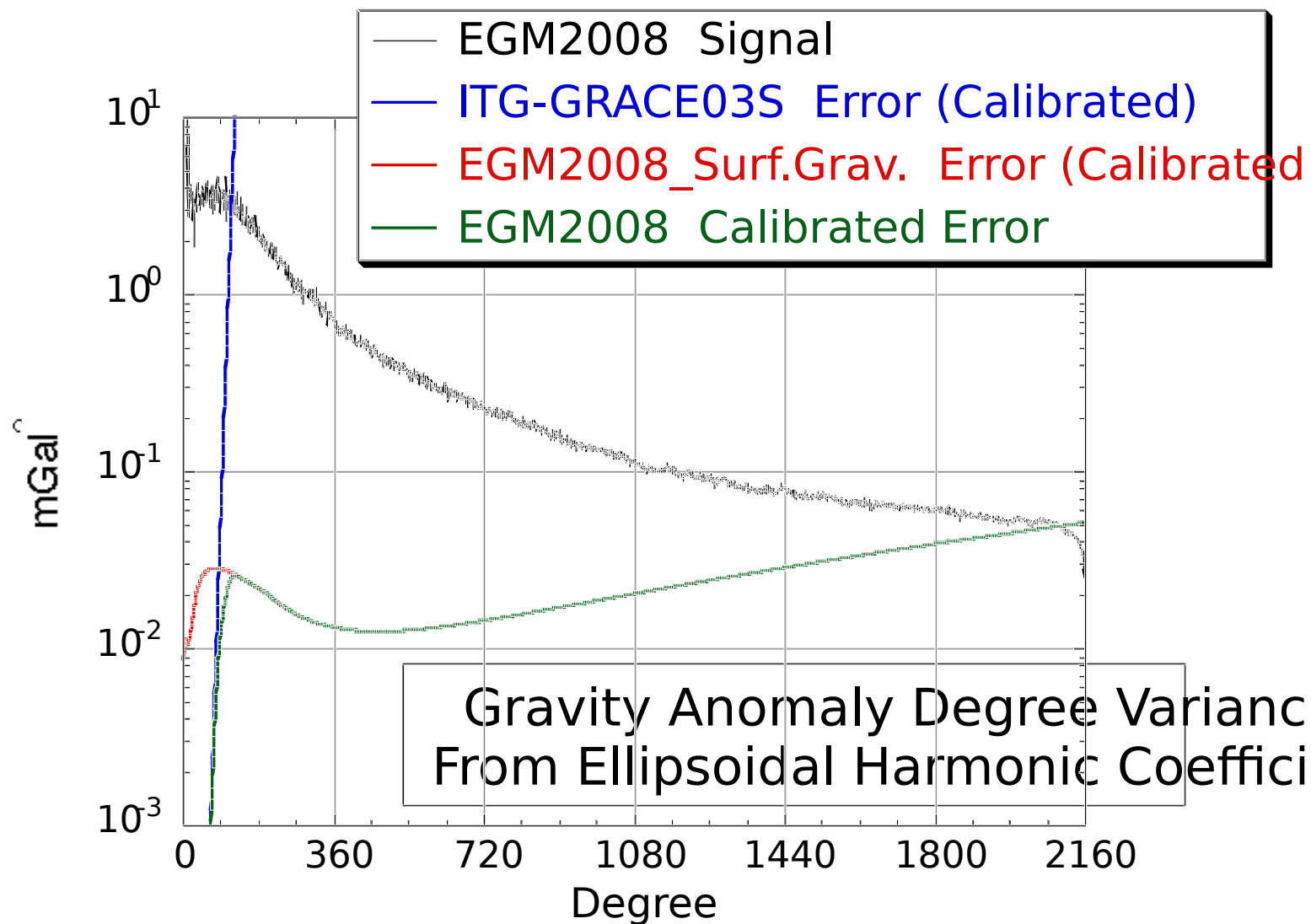
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The Development of EGM2008

- **ITG-GRACE03S** (*Torsten Mayer-Gürr*, 2007), along with its complete error covariance matrix to Nmax=180, was used.

- **Least-Squares Adjustment,** in terms of Ellipsoidal Harmonic coefficients, was used in order to combine the GRACE-only information with the coefficients implied solely by the terrestrial data.

- **Evaluation,** considering residual 5×5′ Δg, GPS/Leveling, Astronomic Deflections of the Vertical, TOPEX Altimetry, the MIT ECCO DOT output, and GRACE KBRR data, was performed.

- **Error Calibration,** to optimize data combination and produce realistic propagated errors for various functionals, up to Nmax=2159, **with** geographic specificity (see *Pavlis and Saleh*, 2004), was performed.

- **EGM2008** does **NOT** incorporate any GPS/Leveling or Astronomic Deflections of the Vertical data.
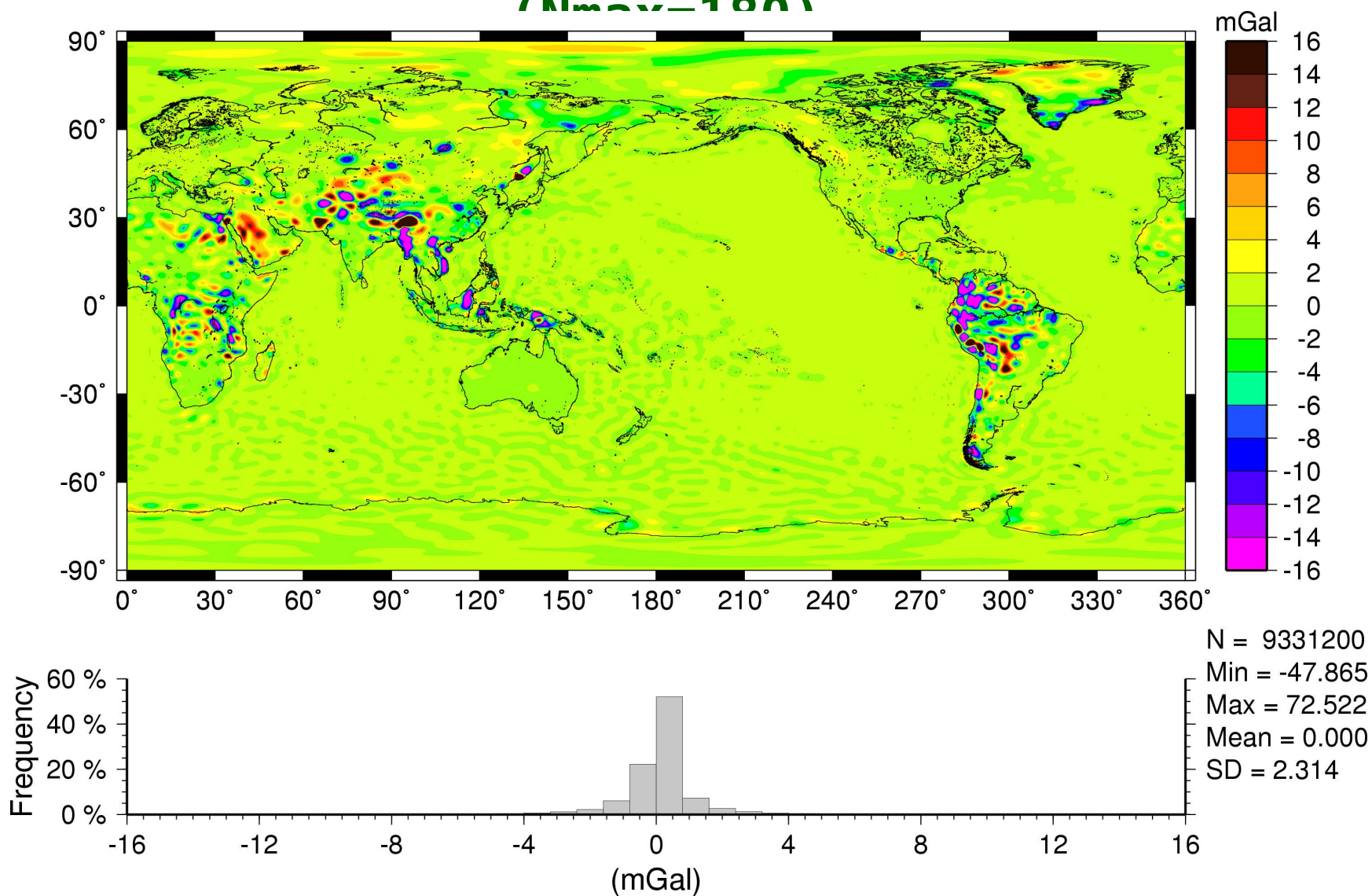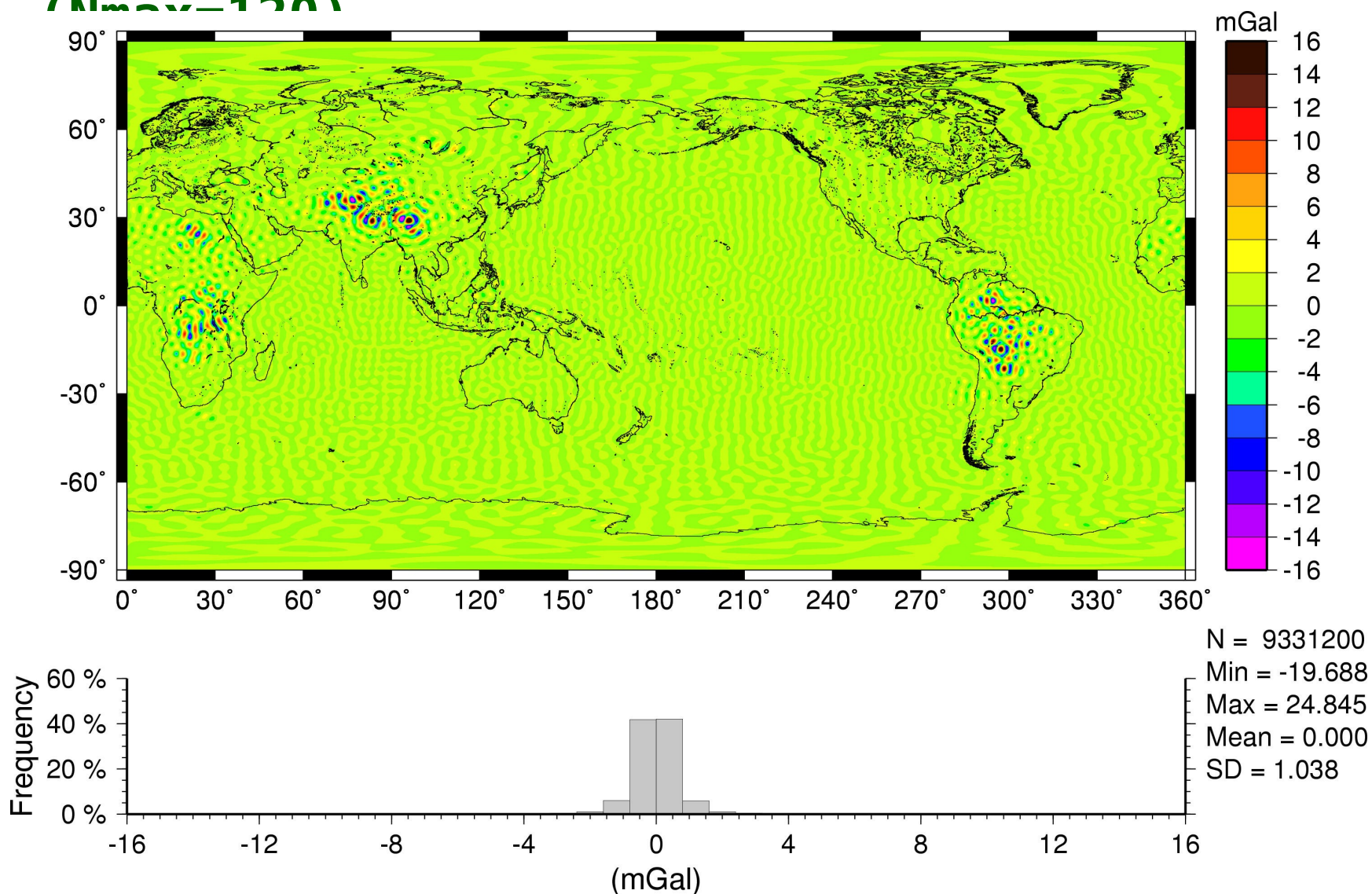
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▶ Spectra Related to the EGM2008 Model

Legend:
— EGM2008 Signal
— ITG-GRACE03S Error (Calibrated)
— EGM2008_Surf.Grav. Error (Calibrated
— EGM2008 Calibrated Error

Gravity Anomaly Degree Varianc
From Ellipsoidal Harmonic Coeffici

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▷ 5´×5 Residual Δg
(Nmax=180)

▷ 5ʹ×5ʹ δΔg   ITG-GRACE03S - EGM2008 (Nmax=120)

N = 9331200
Min = -19.688
Max = 24.845
Mean = 0.000
SD = 1.038

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GPS/Leveling Comparisons Over CONUS

Thinned set consisting of 4201 points. ±2 m edit applied. Analysis by State. Conversion of Height Anomalies to Geoid Undulations applied in EGMs using DTM2006.0 elevation coefficients to commensurate Nmax.

Model (Nmax)	Bias Removed		Linear Trend Removed	
	Number Passed Edit	Weighted Std. Dev. (cm)	Number Passed Edit	Weighted Std. Dev. (cm)
EGM96 (360)	4096	21.4	4092	18.2
GGM02C_EGM96 (360)	4169	18.9	4165	17.6
EIGEN-GL04C (360)	4167	19.5	4163	18.1
EGM2008 (360)	4185	**17.6**	4181	**16.4**
EGM2008 (2190)	4201	**7.1**	4197	**4.8**
USGG03 (1′→10800)	4201	**9.1**	4197	**5.8**

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GPS/Leveling Comparisons Globally

Thinned set consisting of 12387 points. ±2 m edit applied.
Conversion of Height Anomalies to Geoid Undulations applied in EGMs using DTM2006.0 elevation coefficients to commensurate Nmax.

Model (Nmax)	Bias Removed		Linear Trend Removed	
	Number Passed Edit	Weighted Std. Dev. (cm)	Number Passed Edit	Weighted Std. Dev. (cm)
EGM96 (360)	12220	30.3	12173	27.0
GGM02C_EGM96 (360)	12305	25.6	12258	23.2
EIGEN-GL04C (360)	12299	26.2	12252	23.5
EGM2008 (360)	12329	**23.0**	12283	**20.9**
EGM2008 (2190)	12352	**13.0**	12305	**10.3**

▷ ## RMS Differences with Astron. Deflections of Vertical

Model (Nmax)	CONUS 3561 Stations		Australia 1080 Stations	
	ξ	η	ξ	η
EGM96 (360)	2.80	3.22	1.91	2.23
GGM02C_ EGM96 (360)	2.80	3.22	1.89	2.22
EIGEN-GL04C (360)	2.81	3.20	1.92	2.23
EGM2008 (2190)	**1.12**	**1.16**	**1.19**	**1.29**
DEFLEC99 (1´→ 10800)	**0.91**	**0.92**		
AUSGeoid98 (2´→ 5400)			**1.31**	**1.37**

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▷ **6′×6′ ∆SSH: DNSC08B - EIGEN-GL04C (Nmax=360)**

N = 4247328
Min = -482.803
Max = 411.453
Mean = 0.000
SD = 66.578

▶ **6°×6° ∆SSH: DNSC08B - EGM2008 (Nmax=2190)**

N = 4247328
Min = -498.782
Max = 311.993
Mean = 0.000
SD = 63.968

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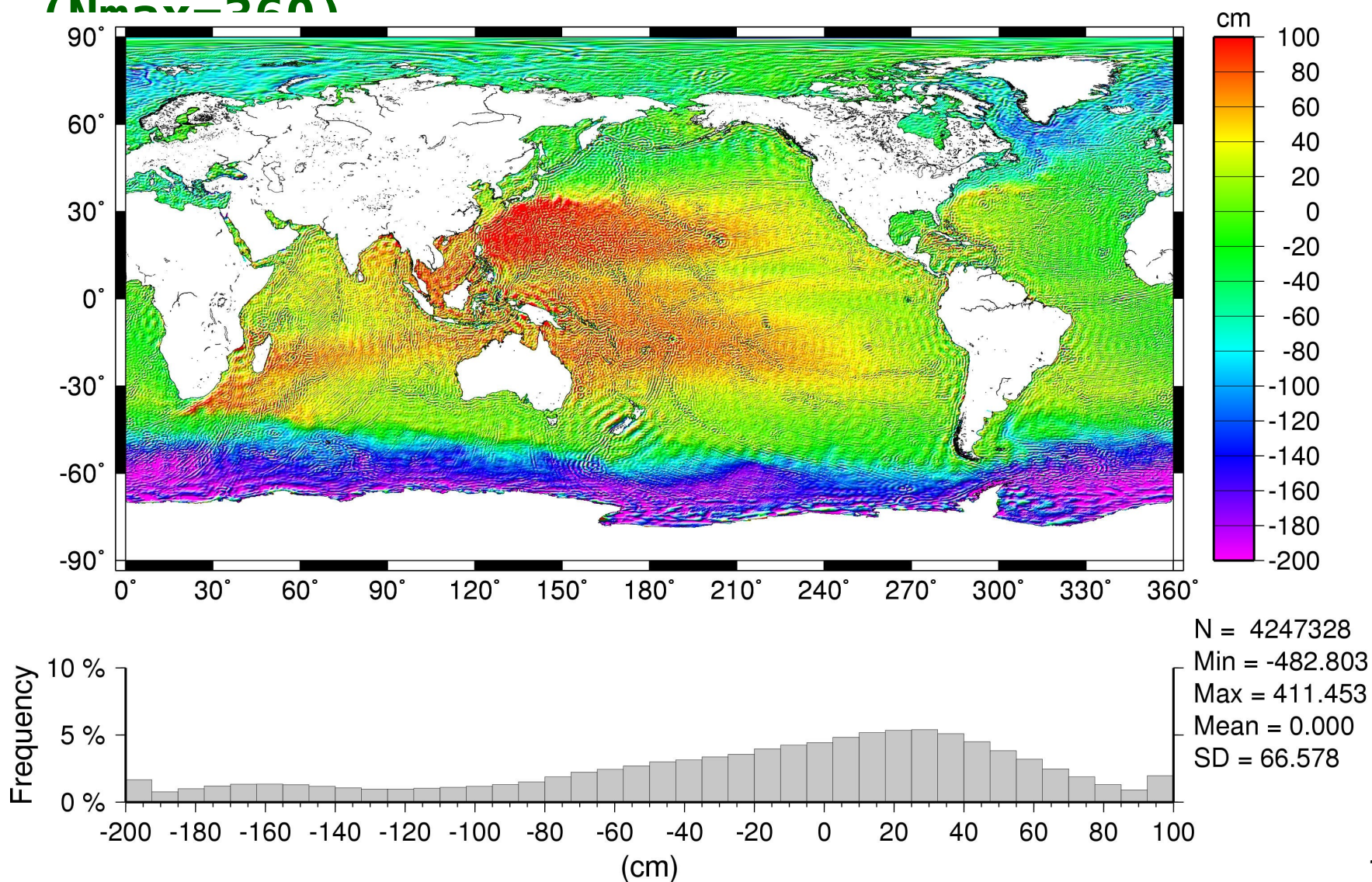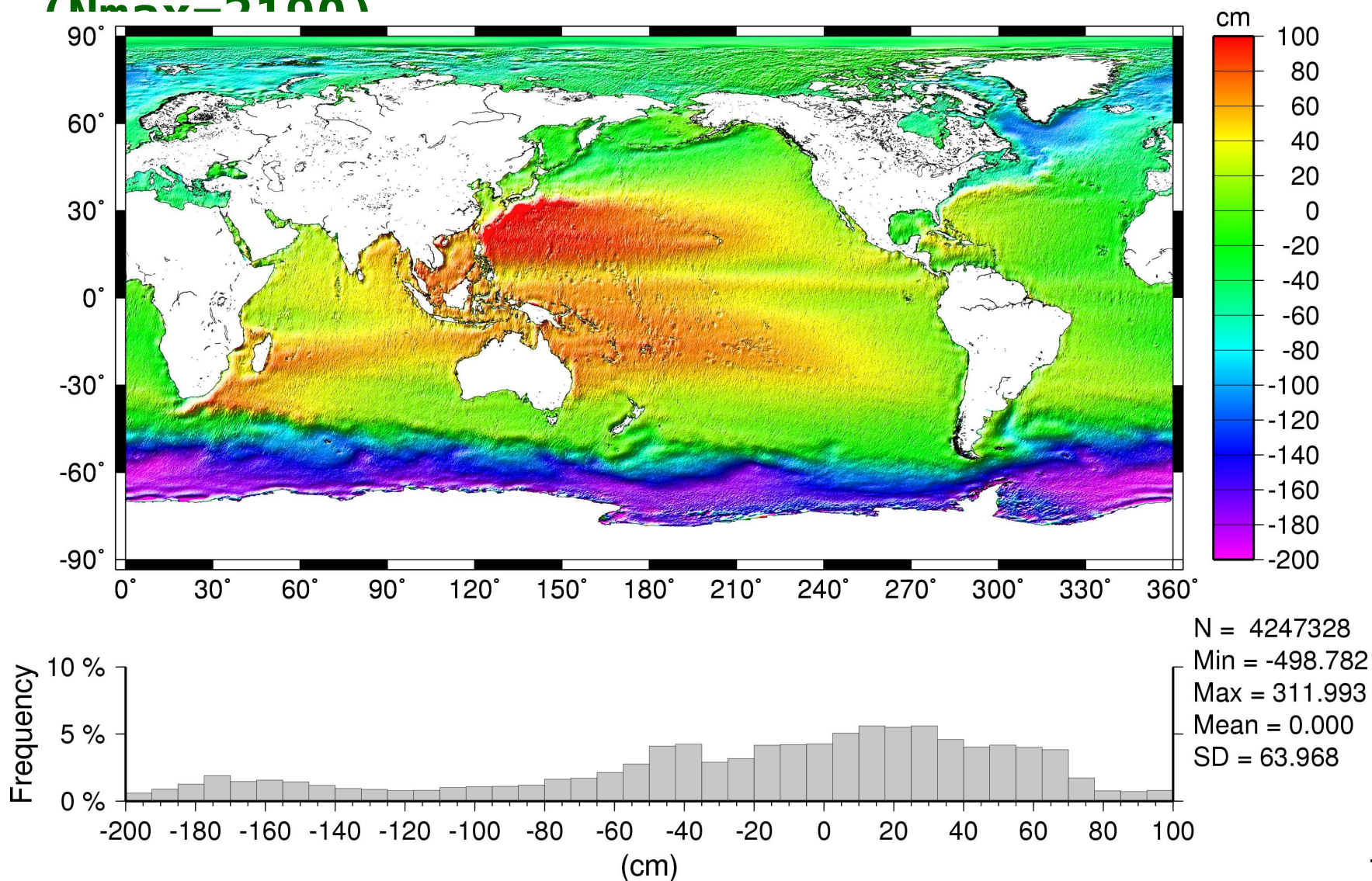
1°×1° ΔDOT: ECCO - EIGEN-GL04C (Nmax=360)

N = 33016
Min = -85.674
Max = 120.328
Mean = -2.315
SD = 10.712
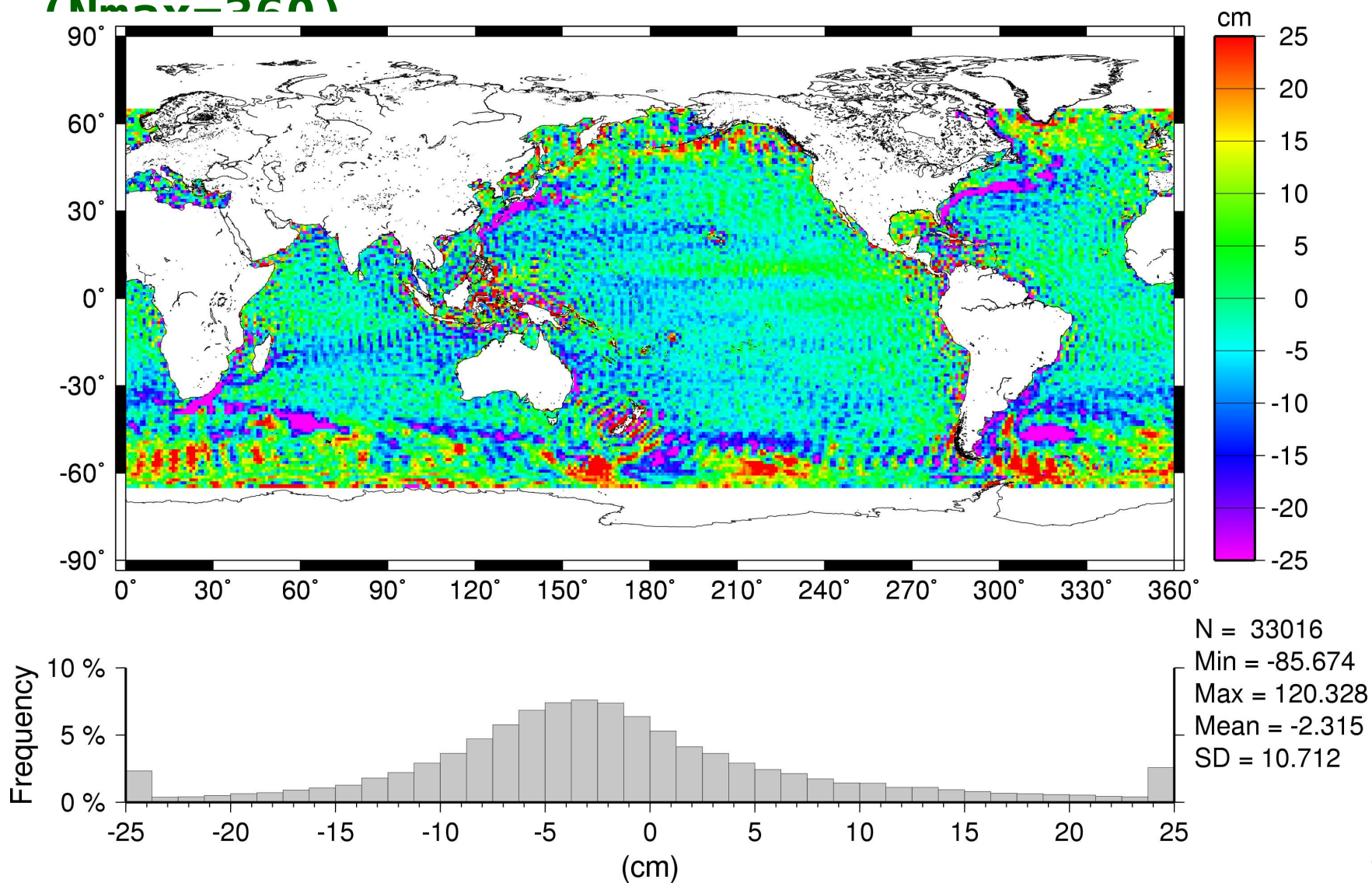
▷ 1°×1° ∆DOT: ECCO - EGM2008 (Nmax=2190)
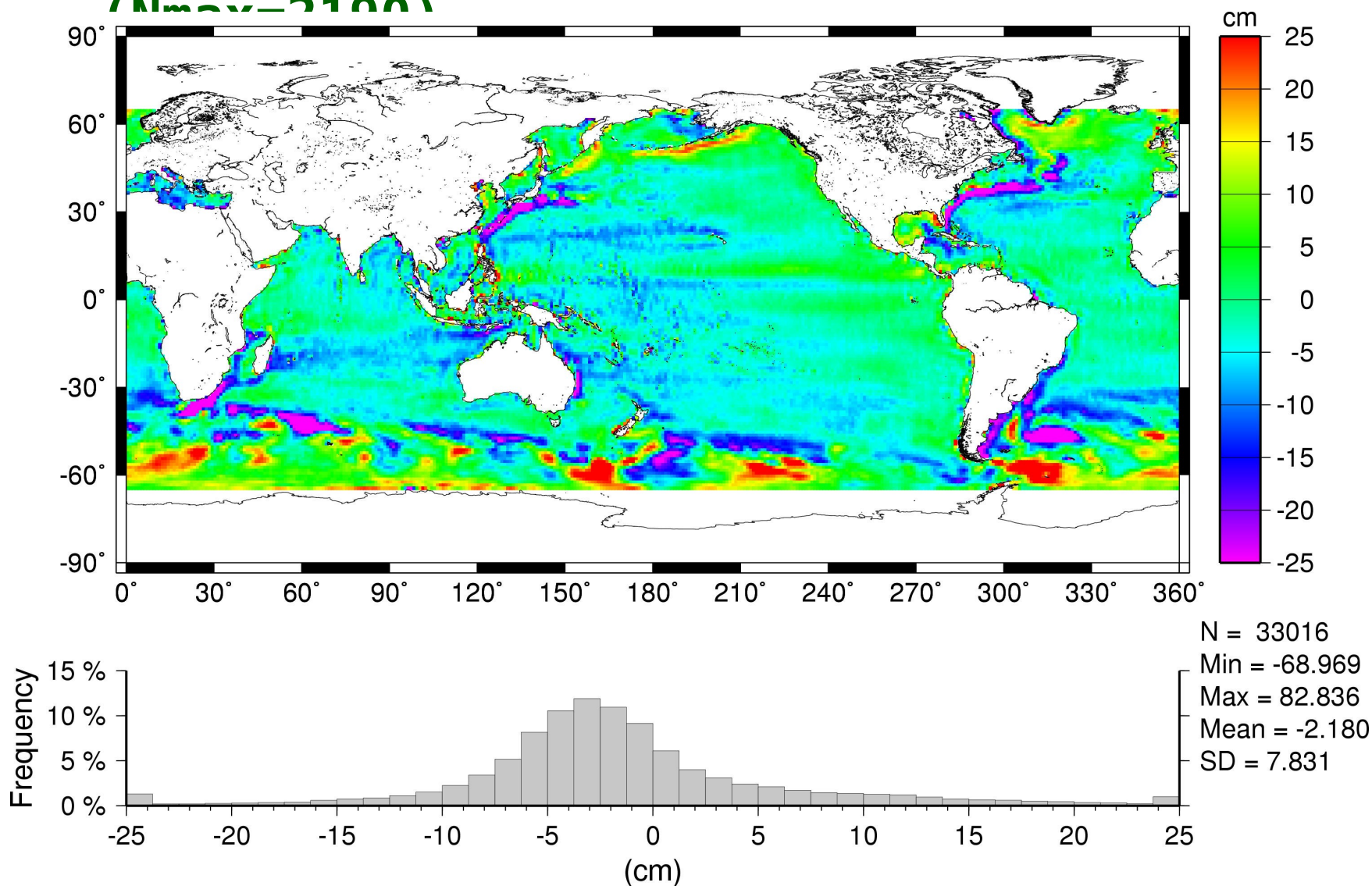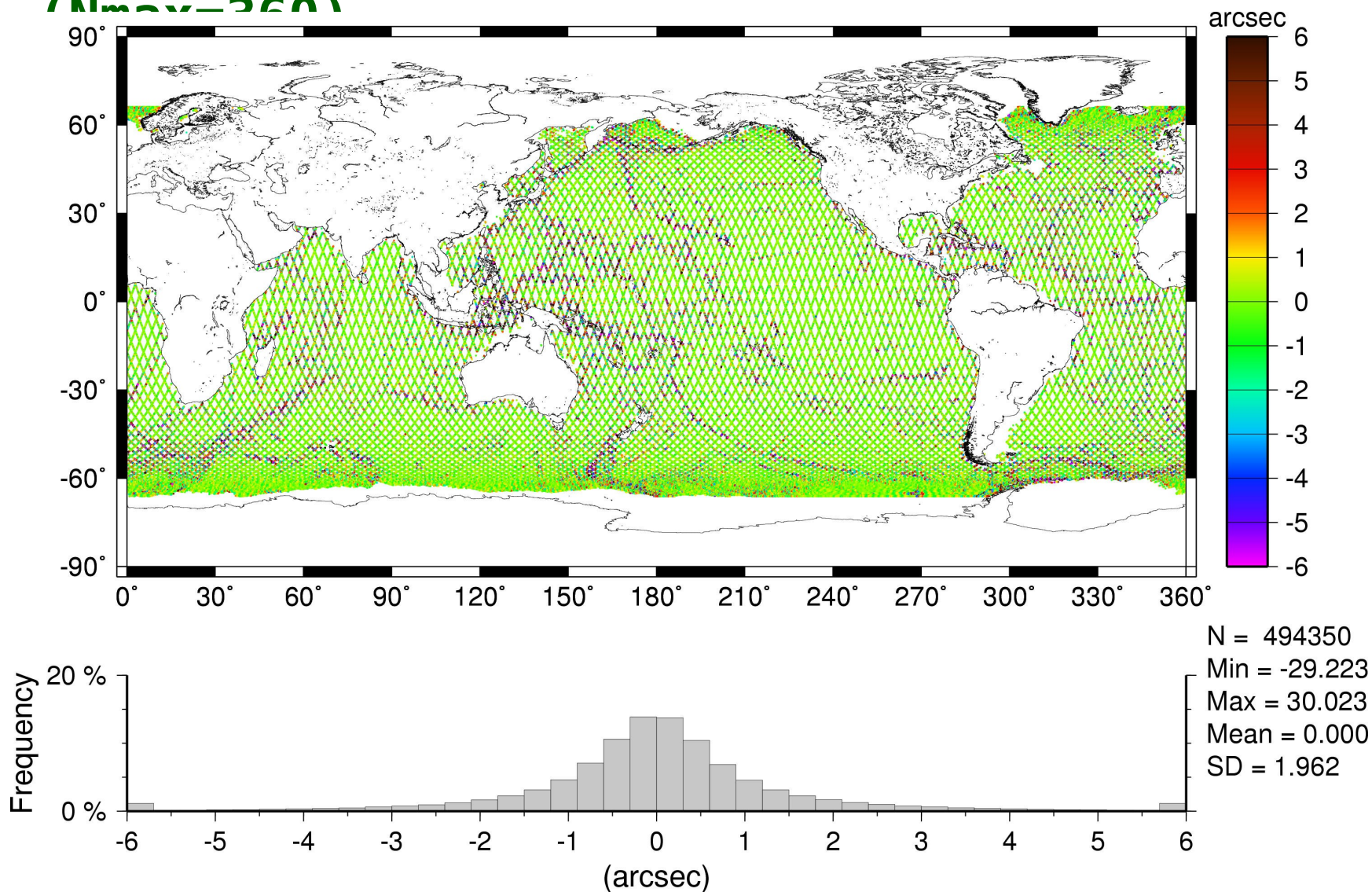
Comparisons with TOPEX/Poseidon Altimetry

6-year mean track 517835 1Hz SSH (494350 Along-Track Slopes). 200 m depth mask used. PGM2007B-derived DOT to Nmax=5.

Model (Nmax)	Residual SSH (cm)		Residual A-T Slope (arc-seconds)	
	max |·|	Std. Dev.	max |·|	Std. Dev.
EGM96 (360)	334	20.0	30.0	1.96
GGM02C_EGM96 (360)	300	18.2	29.3	1.96
EIGEN-GL04C (360)	288	19.2	29.7	1.98
EGM2008 (360)	307	16.0	28.5	1.90
EGM2008 (2190)	**121**	**5.2**	**7.6**	**0.30**

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▷ Residual Sea Surface Slope: EGM96 (Nmax=360)

N = 494350
Min = -29.223
Max = 30.023
Mean = 0.000
SD = 1.962

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▷ Residual Sea Surface Slope: EGM08 (Nmax=2190)

N = 494350
Min = -7.639
Max = 6.644
Mean = 0.000
SD = 0.296

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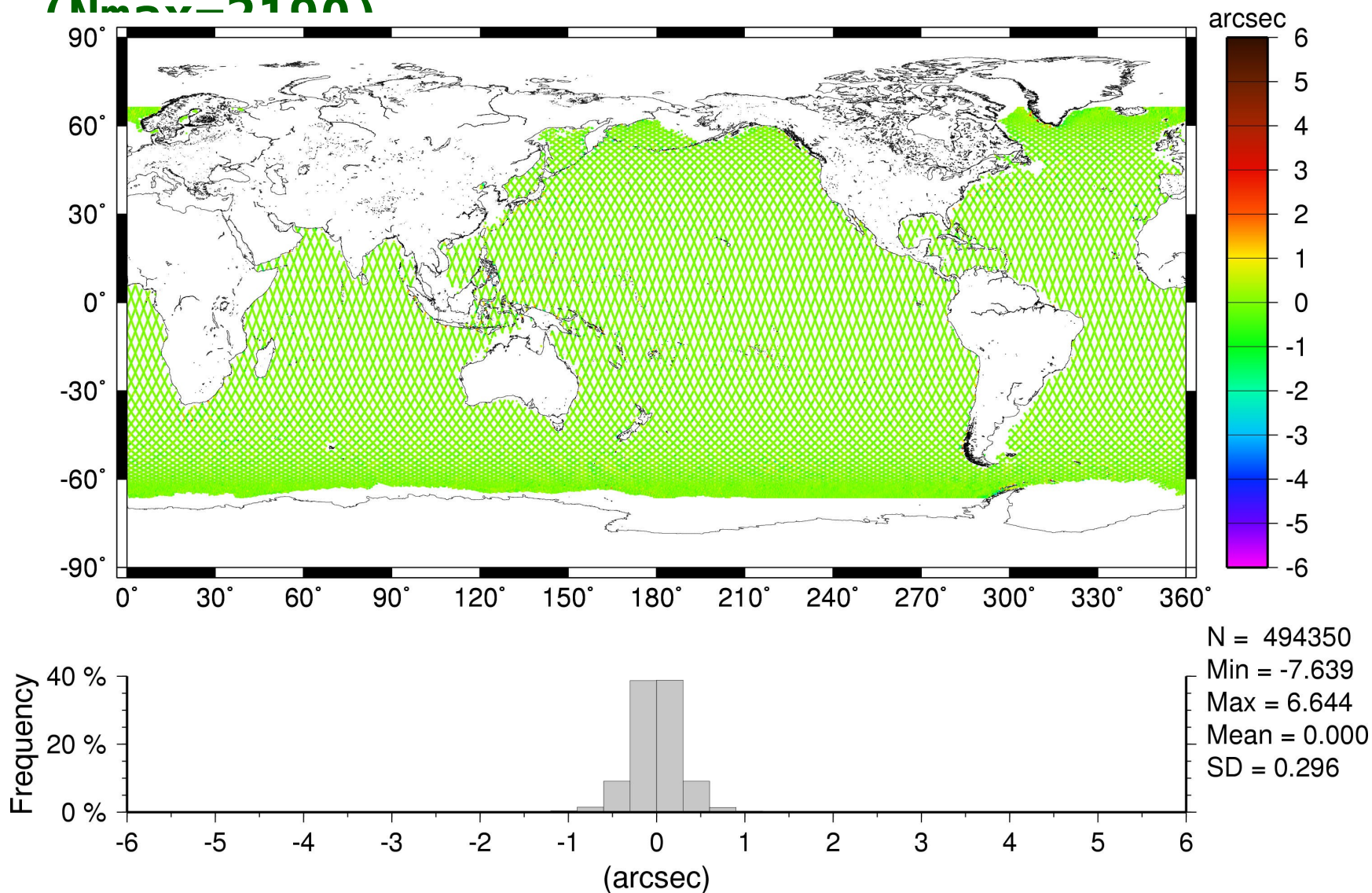
▷ GRACE K-Band Range-Rate RMS Residual per 24-h Arc

Legend:
- ◆ GGM02C   RMS = 0.312 μm/s
- ▼ PGM2007B RMS = 1.520 μm/s
- ▲ EGM2008   RMS = 0.385 μm/s

Y-axis: μm/s
X-axis: Day of Year 2005
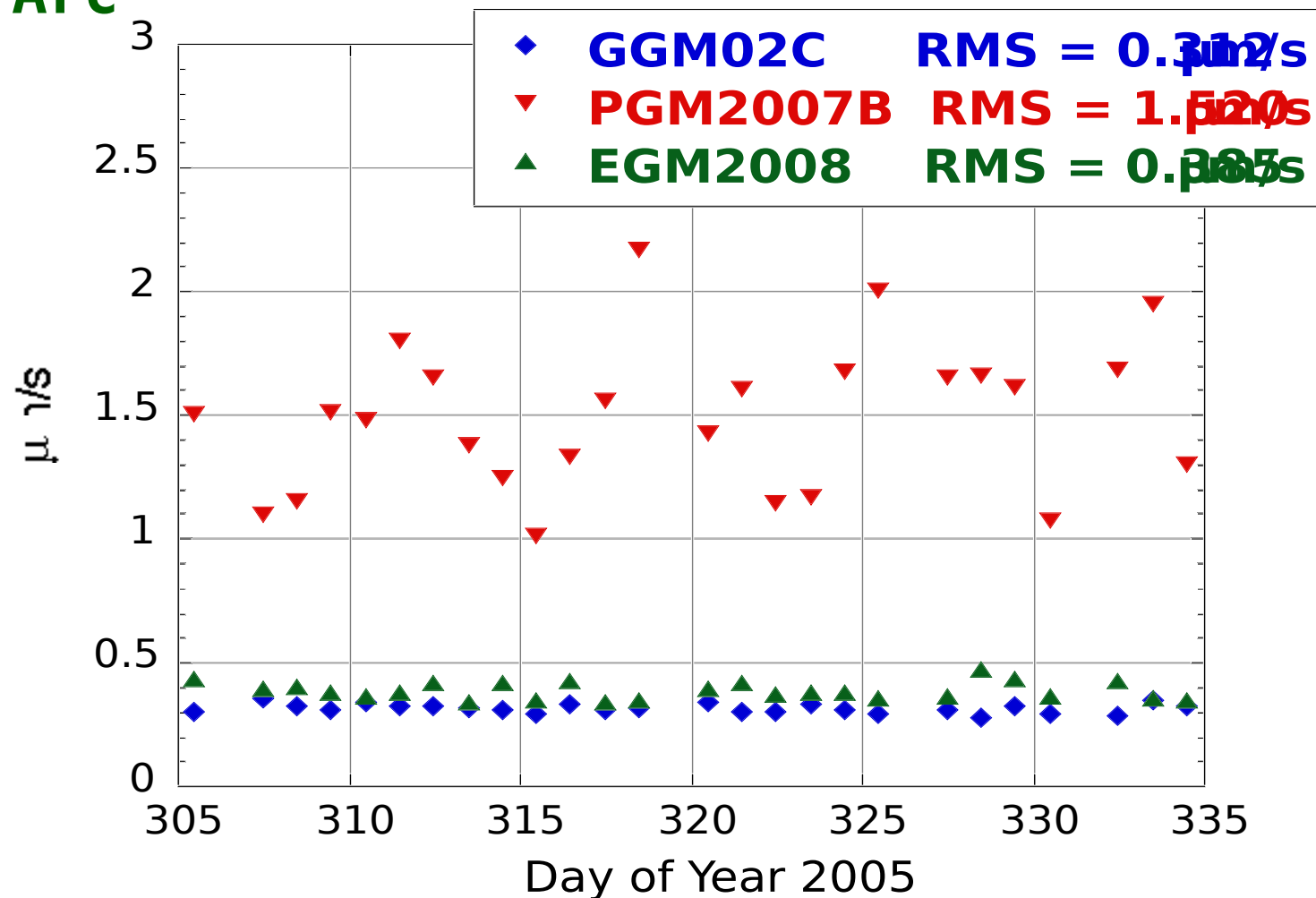
Courtesy of Scott Luthcke (NASA/GSFC)

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▷ **5′×5′ N Commission Error: EGM2008 (Nmax=2159)**

N = 9331200
Min = 3.045
Max = 102.194
RMS = 11.137

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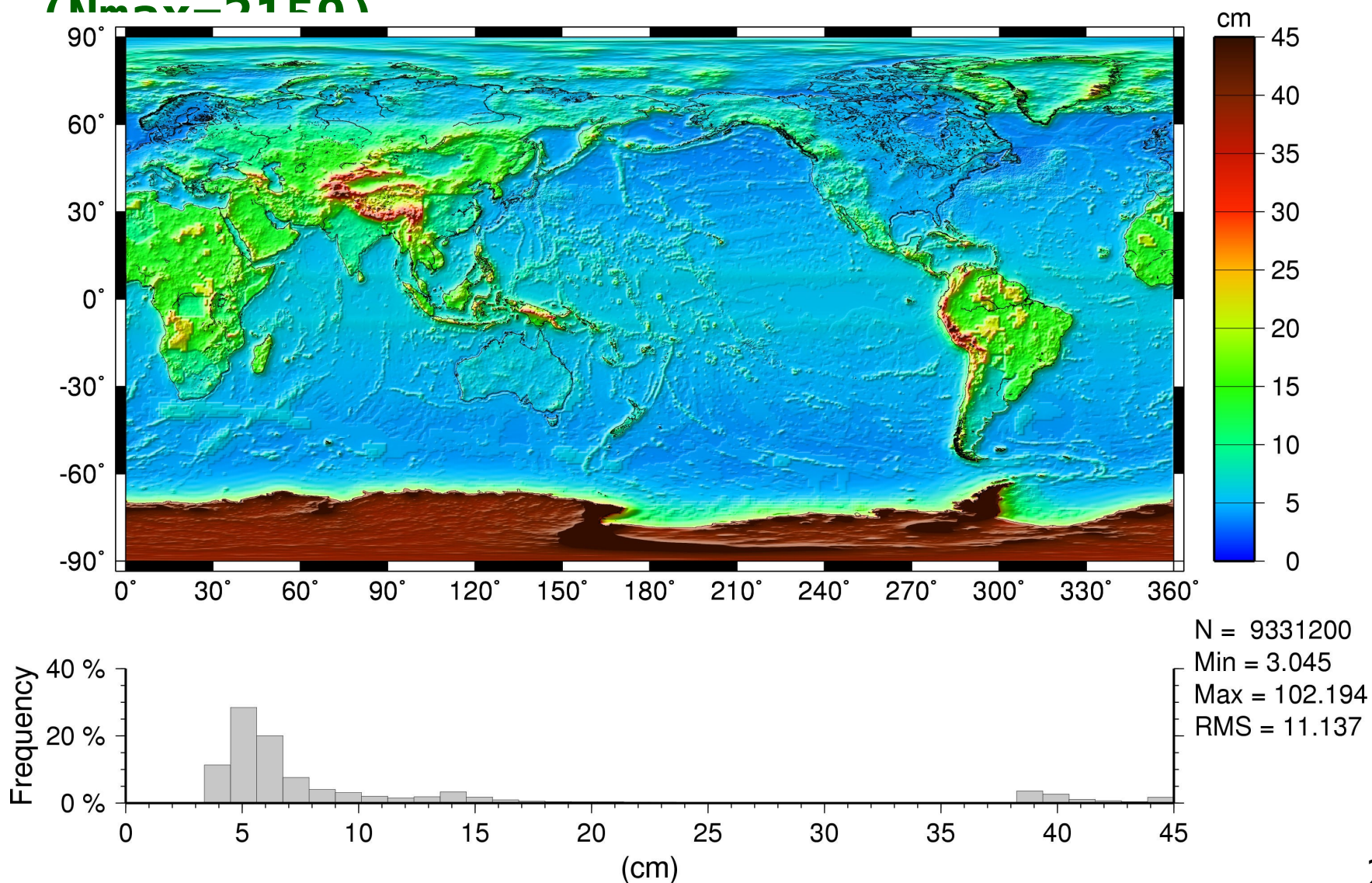
EGM2008 Commission Error Estimates (Nmax=2159)

Parenthetical values represent **observed** performance based on comparisons with independent data. However, the comparison results include also the **omission** error of the model.

Region	RMS (cm)	RMS (arcsec)	RMS (arcsec)
Land Ocean	5.8 (52)	0.38 (~0.30)	0.39 (~0.30)
CONUS	5.9 (48)	0.47 (1.12)	0.47 (1.16)
Land	18.3 (~103)	1.69	1.69
Ocean	6.1	0.42	0.42
Globe	11.1	0.98	0.98

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Summary and Model Availability

- EGM2008 has been developed and is **freely** available.

- Overall, EGM2008 maintains or improves upon the performance of PGM2007A/B for terrestrial applications (geoid undulations, deflections of the vertical, DOT, etc.).

- EGM2008 drastically improves upon the performance of PGM2007A/B for various satellite applications (mostly GRACE-related).

- The EGM2008 model coefficients and related products will soon become widely available from:

http://earth-info.nima.mil/GandG/

http://users.auth.gr/kotsaki/IAG_JWG/IAG_JWG.html

- More EGM2008 evaluation results will be presented at the upcoming GGEO 2008 meeting in Chania, Crete, Greece (June 23-27, 2008):

http://www.geomatlab.tuc.gr/GGEO2008

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▶ Acknowledgements

- We thank Carl Wunsch, Charmaine King, and Patrick Heimbach for providing the ECCO OT output and its associated documentation.

- We thank Michael Watkins and Dah-Ning Yuan from providing the JEM01-RL03B gravitational model and its error covariance matrix, which were used in the development of PGM2007A/B.

- We thank Torsten Mayer-Gürr for providing the ITG-GRACE03S gravitational model and its error covariance matrix.

- We thank all of the members of the Joint IAG/IGFS Working Group, who participate in the evaluation of PGM2007A and EGM2008, for their valuable feedback.

- This work was sponsored by the USA National Geospatial-Intelligence Agency (NGA) through contract No. NMA401-02-9-2001.

- Simon A. Holmes is an NGA contractor with SGT, Inc..

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Backup Slides

THE UNITED STATES OF AMERICA

▷ **Inter-Comparison of Altimetry-Derived 5´×5´ Δg**

Above the diagonal: Area-weighted Mean & Std. Dev. of Differences (mGal)
Below the diagonal: Extreme Differences (mGal)

All: 80N-80S. Npts=5646416. Area=70.025%.

	PGM07B		DNSC07		SS v18.1	
PGM07B			0.000	1.351	-0.047	2.201
DNSC07	-45	42			-0.048	1.939
SS v18.1	-88	114	-74	114		

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▷ GPS/Leveling Comparisons Over Australia (Mainland)

Thinned set consisting of 534 points. ±2 m edit applied.
Conversion of Height Anomalies to Geoid Undulations applied in EGMs using DTM2006.0 elevation coefficients to commensurate Nmax.

Model (Nmax)	Bias Removed		Linear Trend Removed	
	Number Passed Edit	Weighted Std. Dev. (cm)	Number Passed Edit	Weighted Std. Dev. (cm)
EGM96 (360)	533	37.7	533	35.8
GGM02C_EGM96 (360)	534	32.2	534	29.6
EIGEN-GL04C (360)	534	32.7	534	30.1
EGM2008 (360)	534	**29.2**	534	**26.0**
EGM2008 (2190)	534	**26.6**	534	**23.0**
AUSGeoid98 (2→5400)	534	**31.0**	534	**26.1**

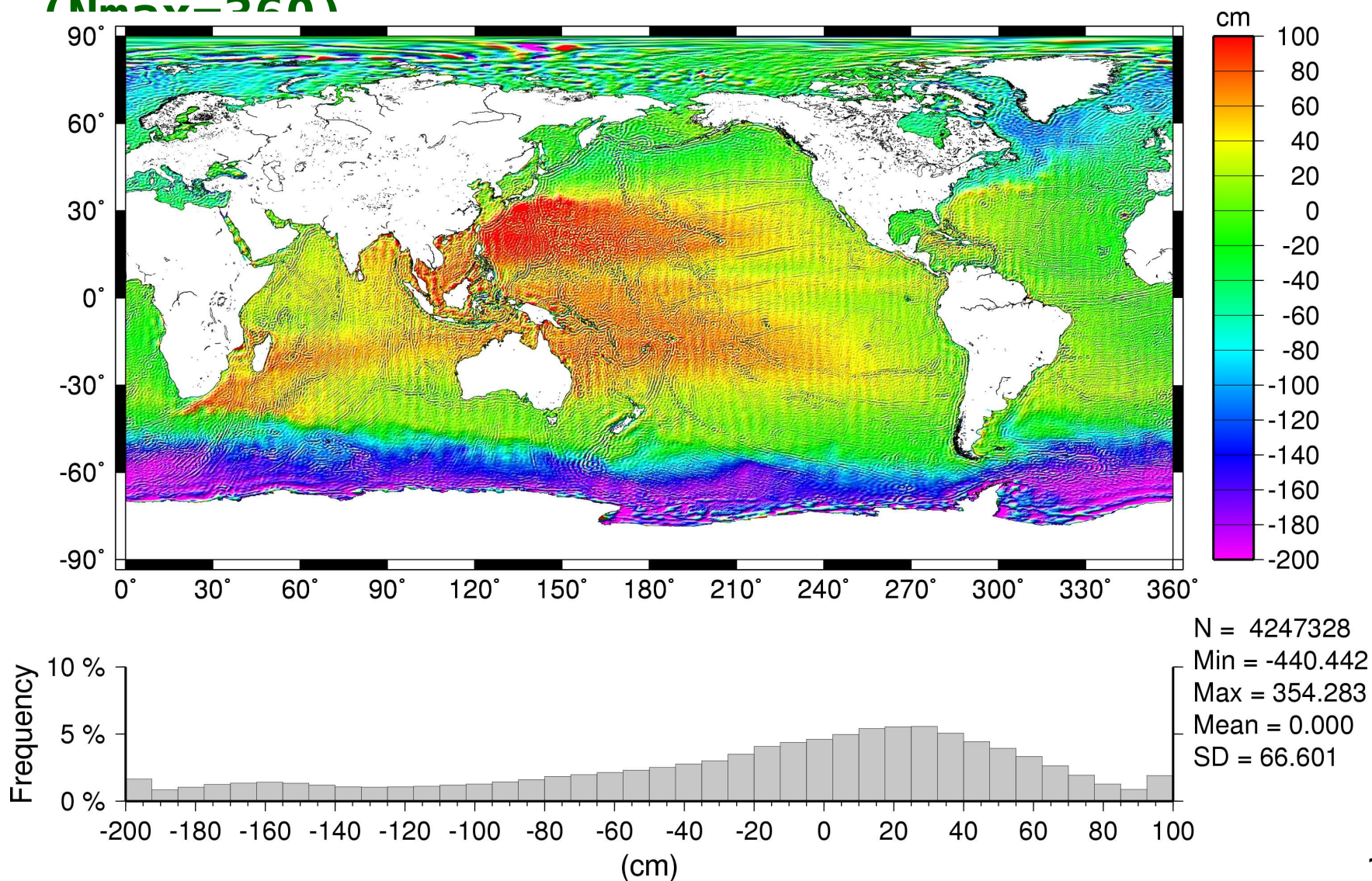## ▷ GPS/Leveling Comparisons Over Australia (SWSZ)

Thinned set consisting of 48 points. ±2 m edit applied.
Conversion of Height Anomalies to Geoid Undulations applied in EGMs using DTM2006.0 elevation coefficients to commensurate Nmax.

Model (Nmax)	Bias Removed		Linear Trend Removed	
	Number Passed Edit	Weighted Std. Dev. (cm)	Number Passed Edit	Weighted Std. Dev. (cm)
EGM96 (360)	48	27.8	48	24.3
GGM02C_EGM96 (360)	48	25.2	48	23.6
EIGEN-GL04C (360)	48	25.7	48	24.9
EGM2008 (360)	48	**23.4**	48	**20.1**
EGM2008 (2190)	48	**10.6**	48	**4.6**
AUSGeoid98 (2′→5400)	48	**12.7**	48	**4.8**

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▷ 6′×6′ ∆SSH: DNSC08B - GGM02C_EGM96 (Nmax=360)

N = 4247328
Min = -440.442
Max = 354.283
Mean = 0.000
SD = 66.601

1°×1° ∆DOT: ECCO - GGM02C_EGM96 (Nmax=360)

N = 33016
Min = -78.206
Max = 113.398
Mean = -2.298
SD = 9.724

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▶ **5′×5′ ξ Commission Error: EGM2008 (Nmax=2159)**

N = 9331200
Min = 0.133
Max = 11.423
RMS = 0.979

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▷ **5ʹ×5ʹ η Commission Error: EGM2008 (Nmax=2159)**

N = 9331200
Min = 0.129
Max = 11.203
RMS = 0.981

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